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MECHANICAL PROPERTIES OF ROCK SAMPLES FROM PINAWA, MANITOBA

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MECHANICAL PROPERTIES OF ROCK SAMPLES FROM PINAWA, MANITOBA

by

A. Annor*

ABSTRACT

CANMET and Ontario Hydro undertook a joint project to investigate the uniaxial mechanical properties of rock samples from Pinawa, Manitoba as part of mechanical properties characterization of rock formations associated with the Canadian Nuclear Fuel Waste Management Program (NFWMP).

The investigations which comprised of uniaxial compression, Brazilian tensile strength, and acoustic wave velocity measurements, were undertaken to provide data and interpretation for vault design and pathway analysis, as well as, to assist other activities and tasks within the Canadian Nuclear Fuel Waste Management Program (NFWMP).

The test results indicated trends of decreasing uniaxial compressive strength, Brazilian tensile strength, and zero pressure compressive wave velocity and increasing Poisson's ratio with depth. For purposes of mechanical properties data interpretation, the Pinawa formation was subdivided into three zones based on the extent of rock alteration.

The results compare favourably with published data for granitic rocks of similar mineralogical compositions as the Lac du Bonnet formation at Pinawa.

In terms of engineering classification (Deere and Miller, 1966), the Pinawa formation falls in the range of high strength to very high strength rock with medium modulus ratio.

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COMPORTEMENT DES PROPRIÉTÉS MÉCANIQUES D'ÉCHANTILLONS DE ROCHES DE PINAWA (MANITOBA)

par

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RÉSUMÉ

CANMET et l'Ontario Hydro ont entrepris un projet mixte pour étudier le comportement des propriétés mécaniques uniaxiales d'échantillons de roches provenant de Pinawa au Manitoba en relation avec le projet de caractérisation des propriétés mécaniques de formation des roches, faisant partie du Programme canadien de gestion des déchets de combustible nucléaire.

Les investigations ont porté sur la mesure de compression uniaxiale, de la résistance à la traction à l'aide de l'essai brésilien et de la vitesse du son afin de recueillir des données dont l'interprétation servira à la conception de voûtes et à l'étude de galeries ainsi qu'à d'autres tâches ou activités.

Les résultats des essais démontrent des tendances à une résistance décroissante à la compression uniaxiale, à la traction d'après l'essai brésilien , une pression nulle pour la vitesse de l'onde de compression et une augmentation du rapport de Poisson avec la profondeur. Afin de faire l'interprétation des données des propriétés mécaniques, on a subdivisé la formation de Pinawa en trois zones selon l'ampleur de l'altération des roches.

Les résultats se comparent favorablement aux données publiées sur les roches granitiques ayant une composition minéralogique semblable à celle du granite de Pinawa.

En ce qui concerne la classification de génie civil (Deere et Miller 1966) la formation rocheuse de Pinawa se range dans la catégorie des roches très résistantes et extrêmement résistantes avec un rapport de module moyen.

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INTRODUCTION

Over the past few years, CANMET and other Branches within Energy, Mines and Resources Canada (EMR) have been involved in a comprehensive geomechanics characterization of various rock bodies, in support of the Canadian Nuclear Fuel Waste Management Program (NFWMP). Studies at CANMET have focused on the following principal areas (Larocque and Annor, 1984).

1. Conventional uniaxial elastic properties characterization of research area formations.
2. Thermo-mechanical properties studies under controlled conditions of temperature and pressure on a few formations.
3. The study of permeability and fracture development, as independent functions of temperature and pressure on a few selected formations.
4. The study of changes in coefficient of thermal expansion under constraint. (For selected formations to complement the thermomechanical and thermal fracturing studies.)
5. Evaluation of rock joint behaviour model, and associated characterization system for assessing coupled mechanical, and hydraulic conductivity behaviour of joints.

The mechanical properties investigations are carried out to provide data and interpretations for vault design and pathway analysis, as well as to assist other activities and tasks (Annor et al. 1979). The uniaxial elastic properties component of the study which this report addresses, has generally been undertaken as a joint project between CANMET and Ontario Hydro.

A number of technical reports summarizing basic test data, and preliminary observations on the uniaxial elastic properties behaviour of research area formations, have been prepared by the principal investigators concerned (Annor and Geller, 1979 a,b; Annor et al. 1979, McKay, 1980). However, to fulfill geosphere modelling, and generic rock properties data base requirements within the NFWMP, a series of reports are being prepared on each of the research area formations, to conform to a joint CANMET and AECL recommended format (Baumgartner, 1983). This report, is structured after the recommended format and has the following objectives:

(i) to provide a summary of the uniaxial mechanical properties data which have been compiled to date for the Lac du Bonnet formation at the WNRE* site within the EMR's Rock Properties Activity,

(ii) to describe in some detail, the methodology followed, and

(iii) to compare the test results to published uniaxial mechanical properties data, on granitic rocks of similar composition to the Lac du Bonnet formation.

GEOLOGICAL DESCRIPTION OF CORE SAMPLES

Test specimens used for the investigations, consisted of R-series standard samples from boreholes WN-1, WN-2 and WN-4 in the Lac du Bonnet batholith, near Pinawa, Manitoba. Standard sample selection within EMR's Rock Property Activity is governed by set criteria (Larocque, 1978), and the samples are distributed as shown in Fig. 1. The standard samples are generally selected to reflect the lithological composition of a borehole, and, as such, are considered to be representative of a formation.

The rock samples are identified according to the borehole depth, in which they were taken in meters (Tables 1 and 2). Comprehensive core log descriptions of the samples are given in the following reports: Katsube et al. (1978); Chernis et al. (1978); Chernis (1979), Kamineni and Dence (1979), Chernis et al. (1979), and Wong (1981). A condensed generalised description of the test samples used for the investigations, as summarized by Wong (1984), is provided below.

Based on Streckeisen's (1976) classification for plutonic rocks, the test specimens consisted of 32 granitic, and two tonalite samples. The samples originated from depths ranging between 24, and 929 m in boreholes WN-1, WN-2 and WN-4.

The granitic samples were generally homogeneous, grey to pinkish, massive and consisted of the following average mineral compositions: about 29.3% quartz, 28.5% K-feldspar, 36.3% plagioclase, 4.3% biotite and muscovite, and 1.6% of all other accessory minerals such as chlorite, magnetite, epidote, apatite, etc. All of tested core samples, were inequigranular and porphyritic; they also contained phenocrysts of K-feldspar and plagioclase.

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The two tonalite samples contained large portions of white oblong shaped plagioclase, porphyroblasts of less than 0.5 to 1.5 cm. These were outlined by clots of hornblende and mica of less than 1.8 cm long. Quartz was interstitial to the plagioclase. The average mineral compositions were about 26.1% quartz, 1.2% K-feldspar, 44% plagioclase, 22.1% biotite and 5.7% of all other accessory minerals such as chlorite, magnetite, epidote, apatite, hornblende and sphene (Wong, 1984). There were no fractures visible in any of the core samples tested.

DESCRIPTION OF MEASUREMENTS

Sample preparation and testing were carried out to conform as closely as possible with the American Society for Testing and Materials (ASTM) standards (ASTM 1971, 1979), and CANMET's Pit Slope Manual Specifications (Gyenge and Herget, 1977). Sample preparation, equipment, and testing procedures are also described in the following reports: Annor, 1984; Annor and Wong, 1984, Annor and Jackson, 1984.

SAMPLE PREPARATION:

Cylindrical test specimens with average length to diameter ratio of about 2.2, were used for the uniaxial compression and dilatational wave velocity measurements described in this report. With regards to the Brazilian tensile strength tests, discs with thickness to diameter ratio of about 1:2 were used.

Test samples were cut slightly larger than their final dimensions, using a water cooled diamond-saw. Sample ends were then ground parallel to each other to within 0.03 mm and at right angles to the longitudinal axis. Hardened steel jigs and a lapping wheel were used for this purpose. Sample dimensions and weight were measured, and recorded for future computations. The samples were tested in a dry state after surface air drying in the Laboratory.

To carry out elastic deformation measurements, strain gauges oriented to measure axial and circumferential strains, were located equidistant from the two ends of the specimen. Gauges of similar orientations were located on the opposite sides of the sample. The axial and circumferential gauges were connected in series, to form single active-gauges. The gauges were used in a half bridge configuration for strain measurements. The gauges used were of the BLH Electronics Co. SR-4, FAE Series.

EQUIPMENT AND TESTING PROCEDURE

Dilatational Wave Velocity Measurements

Axial dilatational wave velocity measurements were carried out on samples already gauged for elastic deformation measurements.

The testing equipment consisted of: transmitting and receiving specimen platens containing piezoelectric transducers, a high voltage pulse generator, a signal amplifier and a Tektronix Type 555 dual-beam oscilloscope with delay sweep and a time base resolution of 0.1 microsecond per centimeter. The velocity equipment was used with a 1.33 MN hydraulic press, to measure sample dilatational wave transit time as a function of applied axial load.

Test samples and transducer assembly were placed between the platens of the hydraulic press and were axially stressed in increments of about 2.7 MPa to a maximum stress level. Due to structural limitations of the transducer platens, the maximum applied stress was 43 MPa for WN-1 and WN-2 samples, and 29 MPa for WM-4 samples. At each incremental stress level, the transmitter piezoelectric transducer excited by a pulse generator, was used to send stress waves into the test sample. These were detected by the receiver piezoelectric transducer. The sweep of the oscilloscope was used with the time delay circuit, to display both the direct pulse and first arrivals of the transmitted pulse, and to measure the travel time.

Prior to individual test samples time delay measurements, the transmitting and receiving platens were placed in direct contact with each other. The zero delay time of the sonic system was then determined, (Annor et al., 1979; Gyenge and Herget, 1977). Sample acoustic velocity (Vp) at each stress level was determined from the relationship:

$$Vp = L/_{(tp-to)} \qquad (1)$$

where L = specimen length (m)

tp = time of transit (s)

to = zero delay time of the sonic system(s)

UNIAXIAL COMPRESSIVE STRENGTH MEASUREMENTS

WN-1 and WN-2 Samples

Equipment used to measure axial and circumferential sample deformation under applied axial load, consisted of two Phillips PR9302 Strain bridges and a Mosleley Autograph 2FRA X-Y recorder. The bridges were used in a half bridge configuration. Axial and circumferential strain gauges were used to provide voltage analog outputs of the axial and circumferential strains produced in the sample by axial loading. These analogs were used to drive the two Y-axis plotters of the 2FRA-X-Y recorder independently . Axial and circumferential stress-strain curves were obtained in this manner for each of the WN-1 and WN-2 samples tested. The curves were used to determine Young's modulus and Poisson's ratio. The axial load was increased until failure occurred. Recorder outputs of the axial stress versus strain curves are provided by Annor and Geller (1979 a,b).

WN-4 Samples

A method similar to that described above, was used for carrying out the uniaxial compression measurements of the WN-4 core samples. Each sample however, was subjected to three loading and unloading cycles to compensate for the effects of stress relaxation due to drilling. Reported Young's modulus and Poisson's ratio, were determined from the average value of the final two loading and unloading cycles (McKay, 1980). Recorder output of the stress versus strain curves are contained in a report by McKay (1980).

Data Treatment

Young's modulus was calculated for each sample by determining the value of the tangent to the axial strain curve at 50% of failure load. The ratio of the tangent to the transverse strain curve to the tangent to the axial strain curve at 50% failure load was used to determine the sample Poisson's ratio. The ultimate compressive strength of each sample was calculated by dividing the sample failure load by sample cross sectional area.

BRAZILIAN TENSILE STRENGTH TESTS

Samples were tested according to ASTM specification C496-71. Test samples were loaded diametrically between two hardened steel platens in a hydraulic press until sample failure occurred.

Data Treatment

The tensile strength of a sample was determined from the relationship:

$$\sigma_t = 2P/\pi Dt \qquad (2)$$

where σ_t = specimen tensile strength (kPa)

P = failure load (N)

D = diameter of disc (cm)

t = thickness of disc (cm)

DATA ANALYSIS AND RESULTS

Basic data for the measurements described above are, provided in Annor and Geller, (1979 a,b) and McKay (1980).

Borehole vertical depth and elevation for each specimen, were estimated from Geological Survey of Canada Directional Survey Reports on boreholes WN-1, WN-2 and WN-4 (Dugal, 1983).

The equivalent overburden pressure (σv), at sample depth was determined from the relationship

$$\sigma_v = \rho g z \text{ (kPa)} \qquad (3)$$

where ρ = density (kgm^{-3})

g = acceleration due to gravity (ms^{-2})

z = depth (m)

DATA SUMMARY

The test results in terms of boreholes, are compiled in Tables 1 to 4. Table 5 summarizes the range, mean and standard deviation values of specimen bulk density, uniaxial compressive strength, tangent modulus of elasticity, Poisson's ratio, zero pressure compressive wave velocity and Brazilian tensile strength, based on rock type.

Depth profiles of uniaxial compressive strength, zero pressure compressive wave velocity, tangent modulus of elasticity, and Poisson's ratio, are provided in figure 2.

Figure 3 shows a relationship between Young's modulus and uniaxial compressive strength for the Lac du Bonnet rock specimens based on the Deere and Miller Classification for Intact Rock (1966). Modulus ratio for this classification is defined as follows:

$$\text{Modulus ratio} = \frac{\text{tangential Young's modulus at 50\% ultimate strength}}{\text{uniaxial compressive strength}} \qquad (4)$$

and is interpreted as follows:

high modulus ratio >500

medium modulus ratio 200 < modulus <500

low modulus ratio <200

Statistical distribution of calculated properties, in terms of sample population, and presented as histograms are also provided in figures 4 to 9.

DISCUSSIONS

In general, the test results show trends of decreasing uniaxial compressive strength, zero pressure compressive wave velocity and Young's modulus, and increasing Poisson's ratio with increasing depth. This behaviour is more pronounced for the WN-4 grey granitic samples which originated below the 450 m depth, than the pink granite samples which were taken above this level.

In terms of the uniaxial compressive strength and acoustic velocity data, the Lac du Bonnet formation (at WNRE), may be sub-divided into three zones. These are: upper, transitional, and lower zones.

Upper Zone

The upper zone, begins from the surface, and extends to a vertical depth of about 450 m. Rock samples tested from this zone, were predominantly granitic in composition. These consisted of, sixteen slightly altered pink granitic, and two tonalite samples (Table 1). The range, mean, and standard deviation values are summarized in Table 5. Densities of the test samples

were very uniform within this zone, and varied between a narrow range of 2.63 to 2.65 Mg/m^3 for the granite rock, and 2.73 to 2.75 Mg/m^3, for the tonalite samples.

Uniaxial compressive strength of samples from the upper zone, varied between 169 and 235 MPa. The mean and standard deviation values were 216 and 17 MPa, respectively for the granitic samples. These should be compared with an average value of 166 MPa, for the two tonalite samples. Brazilian tensile strength values ranged between 7.50 and 12.99 MPa. The mean and standard deviation values were 9.56 and 1.62 MPa, respectively.

Deformational properties of the samples remained relatively uniform within the upper zone. Young's modulus varied between 64.1 and 74.0 GPa. The mean and standard deviation values, were 69.1 and 2.4 GPa, respectively, for the granitic samples. Similarly, Poisson's ratio ranged between 0.20 and 0.30; the mean and standard deviation Poisson's ratio, were 0.24 and 0.03, respectively.

Transitional zone

The transitional zone extends between about 450 m and 660 m vertical depths. This zone bridges the slightly altered pink rock of the upper zone, and the unaltered grey granite of the lower zone. The test samples from this zone were either pinkish, greyish-pink, pinkish-grey or grey in colour.

The range, mean and standard deviation values for the transitional zone samples, are summarized in Table 7. The test results show trends of decreasing uniaxial compressive strength, and compressive wave velocity values, with increasing depth. There are however, no significant changes in deformational properties values between the upper zone, and the transitional zone samples, (Fig. 2).

In general, lower compressive strength, and lower acoustic wave velocity values for rock samples, tend to be associated with increase in porosity (Price 1960; Vutukuri et al. 1974, Wylie et al. 1958). The test results, therefore suggest that there is an increase in rock sample porosity with depth. This occurs below the 450 m vertical depth in borehole WN4, and could be due to significant stress release caused by drilling (Annor and Jackson, 1982).

Lower zone

The lower zone extends from a vertical depth of about 660 m to the lowest test sample depth. Test samples from this zone were mainly grey in colour. The zone is characterized by uniform density, and uniaxial compressive strength, decreasing compressive wave velocities (Vo and Vp), and Young's modulus values with depth. There is also, an increase in Poisson's ratio values with increasing depth, (Fig. 2). The range, mean, and standard deviation values for this zone are summarized in Table 8.

Generalized Observations

In general, the test results suggest that, core samples originating from the lower reaches of borehole WN-4 (Transitional, and Lower Zones), are subject to the effects of stress relaxation. This results in decreasing uniaxial compressive strength, and compressive wave velocity with increasing depth, due to increase in sample porosity. Studies by Katsube et al. (1984), have shown increases in effective porosity and permeability values with increasing depth for WN-4 samples. Acoustic velocity studies on WN-1, WN-2 and WN-4 samples (Annor, in preparation), have also indicated that pressures higher than the overburden stresses equivalent to sample depths, are required to restore test sample compressive wave velocity values within the projected range of the in situ values, as measured by Huang and Hunter (1980). It should be pointed out however that, the laboratory velocity measurements do not take into consideration, the moisture content of the in situ rock mass, hence the above comparison may not apply.

Although laboratory-determined uniaxial strength and deformation data, may not accurately represent in situ rockmass behaviour, in the absence of in situ test data however, the laboratory results can provide essential information, on the possible rockmass response to excavation. In this regard, the test results suggest that, the Lac du Bonnet grey granitic rockmass may be susceptible to the effects of stress relaxation, when excavated. This could occur in the rockmass boardering the excavation.

Additionally, the laboratory test results can be used to infer possible rockmass behaviour in situ. This is possible in cases where sufficient data exist on formations with similar mineralogical compositions. The behaviour of the Lac du Bonnet granitic samples in uniaxial compression, are similar

to those of the Eye Dashewa Lakes pluton, in Ontario, (Table 9). Both formations are of predominantly, granitic compositions. Test samples from either formation, were grey or pink in colour. Pink colouration, has been associated with alteration. On the other hand, grey colour has been identified with the absence of alteration, (Katsube and Kamineni 1983). The unaltered (grey) granitic samples from either formation are weaker in compression, compared to the altered pink samples. This is because, the grey samples are influenced significantly by the effects of stress relief. The pink samples are stronger in compression, because of alternation which reduces the ability of the samples to experience stress relaxation after drilling.

The prevailing in situ stresses in an area, as well as, the in situ fracture density of a rockmass, can be expected to influence the magnitude of stress relaxation, after excavation. For example, core discing during drilling in hard rock, has been associated with a highly stressed ground (Jaeger and Cook, 1968). Although, there has been no record of core discing in the Lac du Bonnet batholith, to date, to suggest the possible existence of extremely high in situ stress fields in this region, high horizontal stress, have been measured in the Canadian shield rock by Herget (1980). It has also been noted from the existing strength, and deformation data on the Eye Dashwa Lakes formation that, rock samples taken from the vicinity of faults were generally weaker in compression due to the effects of stress relief after drilling (Annor and Jackson, 1984). The compressive wave velocity of these samples, were also found to be lower than those of samples taken outside these zones. These findings seem to apply regardless of the state of rock alteration.

Jackson and Boudreau, (1983) have studied the effects of stress relaxation on the elastic deformation, and acoustic wave velocity parameters on Lac du Bonnet granitic samples. The test samples originated from the lower reaches of boreholes at the site of the underground research laboratory. Their results indicated however that, the observed stress relaxation effects on the Lac du Bonnet grey granitic samples, were remedied under relatively low confining pressures. The restoration pressure, was found to be equal to the overburden pressure equivalent to sample depth.

On the basis of current mechanical rock property data, and related geotechnical information on the Lac du Bonnet formation (at WNRE), the existence of extremely high in situ stresses in the region, can not yet be considered to be responsible for the observed trends, of strength and deformation

parameters with depth. Compositional changes between the pink and grey granitic rock, could also account for the observed phenomena.

Additionally it could also be that, the Lac du Bonnet granitic rockmass is susceptible to the effects of stress relaxation. However, the high fracture densities present in the altered zones, allow the rockmass to be stress relieved in situ. In contrast, the low fracture densities of the unaltered zones, prevent in situ stress relaxation of the rockmass, except when excavated.

Experiments are needed to identify the causes of the obvserved trends of mechanical rock parameters with increasing depth.

DATA COMPARISON

In comparison with literature-referenced data, the test results compare favourably with published data for granitic rocks with similar mineral compositions as the Lac du Bonnet formation. Considering the wide range of published data on granitic rocks, the test results were compared only with published data for granitic rock with densities in the range of 2.61 to 2.68 Mg/m^3. A summary of the published reference data is provided in Table 9.

In terms of engineering classification for intact rock by Deere and Miller (1966), the Pinawa granitic formation falls into the range of high strength to very high strength rock, with medium modulus ratio.

SCALING FACTORS

With regards to scaling factors to be applied between the in situ rockmass strength and laboratory determined small scale properties, Hoek and Brown (1980) have suggested the following approximate emperial relationship between uniaxial compressive strength (Qu), and test sample diameter (d), for unjointed intact rock:

$$Qu = Qu_{50} \, (50/d)^{0.18} \qquad (5)$$

(for test sample diameters between 10 and 200 mm)

where Qu_{50} is the uniaxial compressive strength of a specimen of 50 mm diameter.

With respect to deformational properties, Hauze (1980), has determined the following generalized relationship between field and laboratory measured Young's modulus, based on literature review on large geotechnical projects:

$$0.20 < Ef/El < 0.60 \qquad (6)$$

where Ef and El refer to Young's moduli determined in the field and laboratory, respectively.

It is recommended that, some field tests on large volumes of rock be carried out to provide verification data. On the basis of equation 6, the Young's modulus of the Lac du Bonnet granitic rock mass may range between 12 and 38 GPa. When the effects of stress relaxation are taken into consideration, the in situ modulus of the Lac du Bonnet formation may be in excess of 50 GPa.

CONCLUSIONS

The test results indicated a trend of decreasing uniaxial compressive strength, Brazilian tensile strength, Young's modulus and zero pressure compressive wave velocity and increasing Poisson's ratio with increasing sample depth. The trend seems to be more pronounced for the unaltered grey granite samples from the lower reaches of borehole WN-4 than the slightly altered pink rock from boreholes WN-1 and WN-2, and suggest significant stress release effects on the grey granite samples due to drilling.

The existence of extremely high in situ stresses cannot yet be deemed to be responsible for the observed trends with increasing depth. Compositional changes between the grey and pink granitic samples could also account for the observed trends with increasing depth. Additional experiments are required to identify the causes of the observed pehnomena.

For purposes of uniaxial mechanical properties data interpretation, the Lac du Bonnet granite may be sub-divided into upper, transitional and lower zones. The upper zone which consists mainly of slightly altered pink granite, and a small band of tonalite, extends from surface of bedrock to about 450 m vertical depth.

The transitional zone is comprised of a mixture of altered and unaltered rock, and lies between approximately 450 to 660 m vertical depths.

The lower zone extends below the 660 m vertical depth to about maximum test sample depth (830 m) and consists mainly of unaltered grey granitic rock.

The test results compare favourably with literature published data on granitic rock with similar minerological composition as Pinawa granite. In terms of engineering classification for intact rock by Deere and Miller (1966), the Pinawa formation falls in the range of high strength to very high strength rock with medium modulus ratio.

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Table 1 - Summary of uniaxial mechanical properties and dilatational wave velocity data for WN-1 and WN-2 Samples

Specimen identification	Borehole characteristics: Approximate vertical depth (m)	Borehole characteristics: Approximate elevation * (m)	Specimen characteristics: Length (mm)	Specimen characteristics: Diameter (mm)	Specimen characteristics: Density (Mg/m^3)	Compressive strength (MPa)	Elastic modulus (GPA)	Poisson's ratio	Dilatational velocity: Vo (at 0.1 MPa) (Km/s)	Dilatational velocity: Velocity under axial compression: Pressure** (MPa)	Dilatational velocity: Velocity under axial compression: Vp (km/s)	Rock type
WN2- 24.75	23.9	244.5	97.7	44.8	2.63	233	70	0.23	4.9	0.62	4.98	Pink Granite
WN2- 55.45	53.5	214.9	98.5	44.8	2.73	173	74	0.23	5.1	1.43	5.23	Grey Tonalite
WN2- 85.40	82.2	186.2	100.0	46.8	2.75	159	73	0.21	5.4	2.22	5.46	Grey Tonalite
WN2- 98.50	94.7	173.7	97.8	44.7	2.65	232	69	0.21	5.1	2.46	5.26	Pink Granite
WN2-124.70	119.8	148.6	96.1	44.7	2.63	235	69	0.21	4.7	3.09	4.98	Pink Granite
WN1-138.60	133.9	134.6	96.9	44.7	2.64	213	69	0.26	4.8	3.46	4.96	Pink Granite
WN2-145.85	140.0	128.4	96.4	44.8	2.64	224	71	0.21	4.5	3.68	4.78	Pink Granite
WN1-160.90	155.3	113.2	94.5	44.7	2.64	191	66	0.29	4.7	4.02	4.94	Pink Granite
WN1-224.00	215.7	52.8	94.5	44.9	2.64	210	72	0.30	4.8	5.58	5.00	Pink Granite
WN1-246.00	236.7	31.8	95.1	44.9	2.63	219	71	0.20	4.7	6.10	5.01	Pink Granite
WN1-294.50	282.8	-14.3	95.5	45.1	2.64	205	71	0.27	4.8	7.32	5.14	Pink Granite
WN1-303.50	291.3	-22.8	97.2	45.0	2.63	224	67	0.24	4.7	7.51	5.14	Pink Granite
WN1-345.50	330.9	-62.4	95.2	44.9	2.63	227	70	0.24	4.8	8.53	5.10	Pink Granite
WN1-384.80	367.7	-99.2	95.9	44.7	2.66	219	69	0.29	4.9	9.59	5.35	Pink Granite
WN1-410.70	391.8	-123.3	93.8	44.7	2.63	231	73	0.22	4.8	10.10	5.18	Pink Granite
WN1-460.60	438.2	-169.7	97.7	45.0	2.63	214	64	0.24	4.3	11.29	4.84	Pink Granite

* Elevations are with reference to seal level

** Equivalent overburden pressure at sample depth

Table 2 - Summary of uniaxial mechanical properties and dilatational wave velocity data for WN-4 Samples

Specimen identification	Borehole characteristics		Specimen characteristics			+ Compressive strength	+ Elastic modulus	+ Poisson's ratio	+ Dilatational velocity			Rock type and special features
	Approximate vertical depth (m)	Approximate elevation * (m)	Length (mm)	Diameter (mm)	Density (Mg/m^3)	(MPa)	(GPa)		Vo (at 0.1 MPa) (km/s)	Velocity under axial compression Pressure** (MPa)	Vp (km/s)	
WN4-409.00	389.7	-120.9			2.65	211	67.8	0.21	4.41	10.12	5.11	Pink Granite
WN4-469.25	445.3	-176.5			2.65	169	66.1	0.23	4.12	11.56	5.23	Pink Granite
WN4-482.30	457.1	-188.3			2.65	182	66.5	0.23	3.62	11.88	4.63	Pink Granite
WN4-505.57	478.2	-209.4			2.64	217	74.9	0.20	3.96	12.38	4.94	Pink Granite
WN4-551.45	519.5	-250.7			2.65	166	71.4	0.25	3.91	13.49	4.76	Pink Granite
WN4-564.40	531.0	-262.2			2.66	192	78.7	0.25	3.78	13.84	4.80	Pink Granite
WN4-603.60	565.6	-296.8			2.65	168	72.1	0.28	3.90	14.70	4.78	Pink Granite
WN4-631.70[a]	590.2	-321.4			2.64	95	27.4	0.22	3.45	-	-	Greyish Pink Granite
WN4-660.30	614.8	-346.0			2.65	165	69.7	0.25	3.56	15.96	4.50	Grey Granite
WN4-692.70	642.4	-373.6			2.64	168	68.9	0.27	3.69	16.62	4.75	Pinkish-Grey Granite
WN4-719.10	664.4	-395.6			2.64	158	68.6	0.23	3.36	17.20	4.59	Pinkish-Grey Granite
WN4-747.20	687.8	-419.0			2.66	181	64.4	0.34	2.96	17.93	4.54	Grey Granite
WN4-789.90	722.8	-454.0			2.65	155	60.7	0.32	3.20	18.77	4.29	Grey Granite
WN4-809.70	738.7	-469.9			2.66	166	56.5	0.26	2.60	19.25	4.23	Grey Granite
WN4-841.10	763.5	-494.7			2.65	171	62.9	0.25	2.63	19.83	4.16	Grey Granite
WN4-863.60	781.1	-512.3			2.62	147	59.1	0.39	2.89	20.08	4.50	Grey Granite
WN4-906.80	813.9	-545.1			2.65	165	63.8	0.34	2.47	21.15	4.37	Grey Granite
WN4-928.30	829.7	-560.9			2.65	151	59.4	0.27	2.50	21.56	4.11	Grey Granite

* Elevations are with reference to seal level

** Equivalent overburden pressure at sample depth

\+ Basic data was provided by Ontario Hydro (McKay, 1980)

a Data excluded from mean and standard deviation computations

Table 3 - Summary of Brazilian tensile strength data for borehole WN-1 samples

Specimen identification		Tensile strength (MPa)
WN1-324.50	A	8.2
to	B	9.9
WN1-324.60	C	7.5
	D	10.0
	E	8.8
	F	8.5
	G	9.5

Table 4 - Summary of Brazilian tensile strength data for borehole WN-4 samples

Specimen identification	Borehole characteristics: Approximate vertical depth	Borehole characteristics: Approximate elevation (m)	+ Tensile strength (MPa)
WN4 409.00	389.7	-120.9	10.64
WN4 469.25	445.3	-176.5	12.99
WN4 482.30	457.1	-188.3	10.47
WN4 505.57	478.2	-209.4	12.44
WN4 551.45	519.5	-250.7	11.21
WN4 564.40	531.0	-262.2	11.52
WN4 603.60	565.6	-296.8	12.06
WN4 631.70	590.2	-321.4	11.87
WN4 660.30	614.8	-346.0	11.06
WN4 692.70	642.4	-373.6	11.37
WN4 719.10	664.4	-395.6	11.65
WN4 747.20	687.8	-419.0	8.64
WN4 789.90	722.8	-454.0	11.36
WN4 809.70	738.7	-469.9	8.66
WN4 841.10	763.5	-494.7	11.45
WN4 863.60	781.1	-512.3	10.66
WN4 906.80	813.9	-545.1	11.52
WN4 928.30	829.7	-560.9	10.33

+ Basic data was provided by Ontario Hydro (McKay, 1980)

Table 5 - Statistical summary of mechanical properties data for Pinawa granite and tonalite samples

Borehole identification	Principal rock type		Density (Mg/m^3)	Compressive strength (MPa)	Young's modulus (GPa)	Poisson's ratio	P-Wave velocity at zero press. (km/S)	Velocity at overburden press. (km/s)	Brazilian tensile strength (MPa)
WN-1,2, & 4 (combined)	Granite - (unaltered and slightly altered) and tonalite	No. of Values	34	33	33	34	34	33	18
		Range	2.62 to 2.75	147 to 235	56.5 to 78.7	0.20 to 0.39	2.47 to 5.4	4.11 to 5.46	8.64 to 12.00
		Mean	2.65	192	68.2	0.25	4.14	4.84	11.12
		Std. Dev.	0.03	29	4.9	0.04	0.84	0.36	1.12

Table 6 - Statistical summary of mechanical properties data for Upper Zone rock samples (Borehole WN-1, WN-2 and WN -4)

Borehole identification	Principal rock type		Density (Mg/m^3)	Compressive strength (MPa)	Young's modulus (GPa)	Poisson's ratio	P-wave vel. at zero pressure (km/s)	P-wave vel. at overburden pressure (km/s)	Brazilian tensile strength (MPa)
WN-1, WN-2, WN-4 (23.9 to 450 m vertical depth)	Granite and tonalite	No. of values	18	18	18	18	18	18	9
		range	2.63 to 2.75	159 to 235	64 to 74	0.20 to 0.30	4.12 to 5.40	4.78 to 5.46	7.50 to 12.99
		mean	2.65	211	69.6	0.24	4.75	5.09	9.56
		Std. Dev.	0.03	23	2.7	0.03	0.30	0.18	1.62
WN-1 WN-2 WN-4	Granite	no. of values	16	16	16	16	16	16	9
		range	2.63 to 2.66	169 to 235	64 to 73	0.20 to 0.30	4.12 to 5.10	4.78 to 5.35	7.50 to 12.99
		Mean	2.64	216	69.1	0.24	4.69	5.06	9.56
		Std. Dev.	0.01	17	2.4	0.03	0.25	0.15	1.62
WN2	Tonalite	No. of Values	2	2	2	2	2	2	
		range	2.73 to 2.75	159 to 173	73 to 74	0.21 to 0.23	5.1 to 5.4	5.23 to 5.46	
		Mean	2.74	166	73.5	0.22	5.25	5.35	
		Std. Dev.	0.01	10	0.7	0.01	0.21	0.16	

Table 7 - Statistical summary of mechanical properties data for transitional zone rock samples (Borehole WN -4)

Borehole identification	Principal rock type		Density (Mg/m^3)	Compressive strength (MPa)	Young's modulus (GPa)	Poisson's ratio	P-wave vel. at zero pressure (km/s)	P-wave vel. at overburden pressure (km/s)	Brazilian tensile strength (MPa)
WN4 Vertical depth (450-660m)	Granite (altered & unaltered) pinkish to greyish colour	No. of values	7	7	7	7	7	7	8
		range	2.64 to 2.66	165 to 217	68.5 to 78.7	0.20 to 0.28	3.56 to 3.96	4.50 to 4.94	10.47 to 12.99
		mean	2.65	180	72.0	0.25	3.77	4.74	11.50
		Std. Dev.	0.01	19	3.7	0.03	0.16	0.14	0.62

Table 8 - Statistical summary of mechanical properties data for lower zone rock samples (Borehole WN-4)

Borehole identification	Principal rock type		Density (Mg/m^3)	Compressive strength (MPa)	Young's modulus GPa)	Poisson's ratio	P-wave vel. at zero pressure (km/s)	P.wave vel. at overburden pressure (km/s)	Brazilian tensile strength (MPa)
WN-4 vertical depth (660-830m)	Granite unaltered	No. of values	8	8	8	8	8	8	8
		range	2.62 to 2.66	147 to 181	56.5 to 68.6	0.23 to 0.39	2.47 to 3.36	4.11 to 4.59	8.64 to 11.65
		mean	2.65	162	61.9	0.30	2.83	4.35	10.53
		Std. Dev.	0.01	11	3.8	0.06	0.33	0.18	1.25

Table 9 - Summary of literature-referenced uniaxial mechanical properties data for Granitic Rocks

	Location and granitic rock description		Uniaxial density ρ (Mg/m^3)	Compressive strength Qu (MPa)	Modulus of elasticity E (GPa)	Poisson's ratio ν	Tensile strength σ_t (MPa)	Reference
1	U.S.A. Md., contains quartz and syenite		2.65	250.97	52.54	-	20.68 (R)	Wuerker, 1956
2	U.S.A. Pikes Peak, dense, mg		2.64	226.0	70.6	0.18	11.9	Miller, 1965
3	U.S.A. Barre, Vt, and syenite		2.64	194.4	61.4	0.39	10.7	Miller, 1965
4	U.S.A. Rose Granite Pedernal Hills, N.M.		2.64	308.0	69.64	0.28	-	Michalopoulos and Triandafilidis, 1976
5	U.S.A. Raymond, Calf. Raymond granite		2.64	178.0	58.6	0.26	-	Michalopoulos & Triandafilidis, 1976
6	Canada, Grenville Que, Cg, 80% orthoclase		2.61	172.0	65.8	-	-	Coates & Parsons, 1966
7	U.S.A., Barre, Vt. Perpendicular to bedding		2.64	200.0	58.6	-	13.5	Hawkes et al. 1973
8	U.S.A., Mg-Cg	(a)	2.66	228.91	30.4*	0.04*	19.99	Obert et al. 1946
		(b)	2.66	225.15	27.4*	0.10	25.37 (R)	
		(c)	2.66	244.07	44.2*	0.31*	18.41 (R)	
9	Atikokan granite (N=50 samples)	Mean	2.65	212	73.9	0.26	-	Annor and Jackson, 1982
		Std. Dev.	0.02	26	15.2	0.05		
10	Lac du Bonnet granite (URL site)		(N=32)	(N=46)	(N=46)	(N=46)	(N=16)	Annor and Jackson, 1982
		Mean	2.59	185	66.8	0.27	8.9	
		Std. Dev.	0.02	24	9.0	0.05	1.0	

Numbers 1-8 were compiled and condensed from: Lama and Vutukuri (1978)

* Dynamic test values

R - refers to test in bending

ROCK PROPERTY ACTIVITY; STANDARD SAMPLE DISTRIBUTION SCHEME (1979/80)

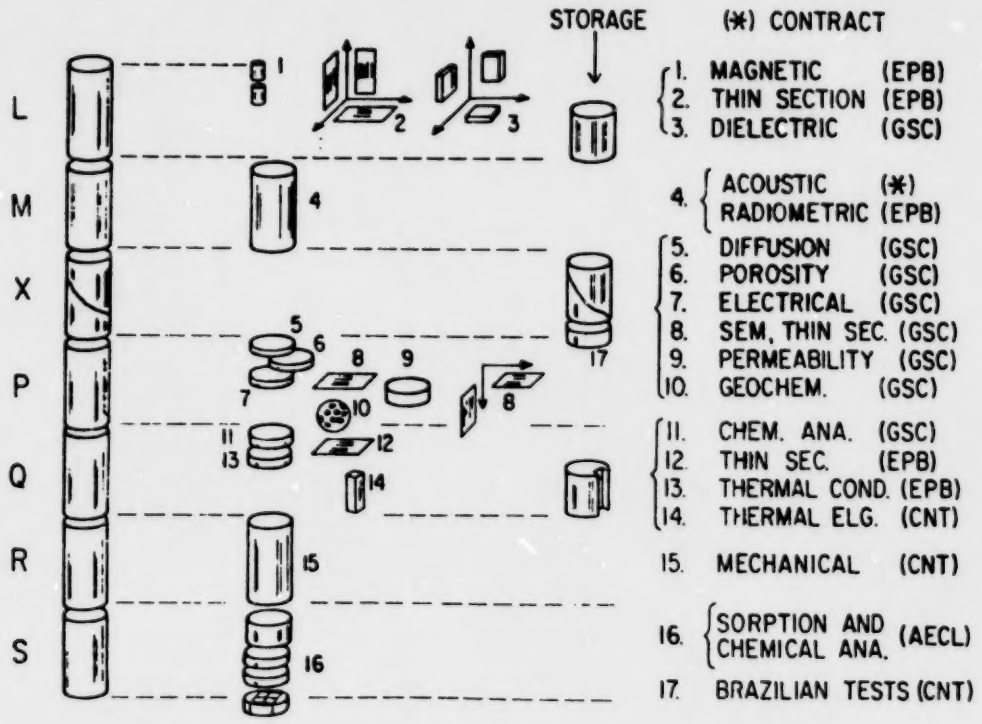

Figure 1: Standard sample

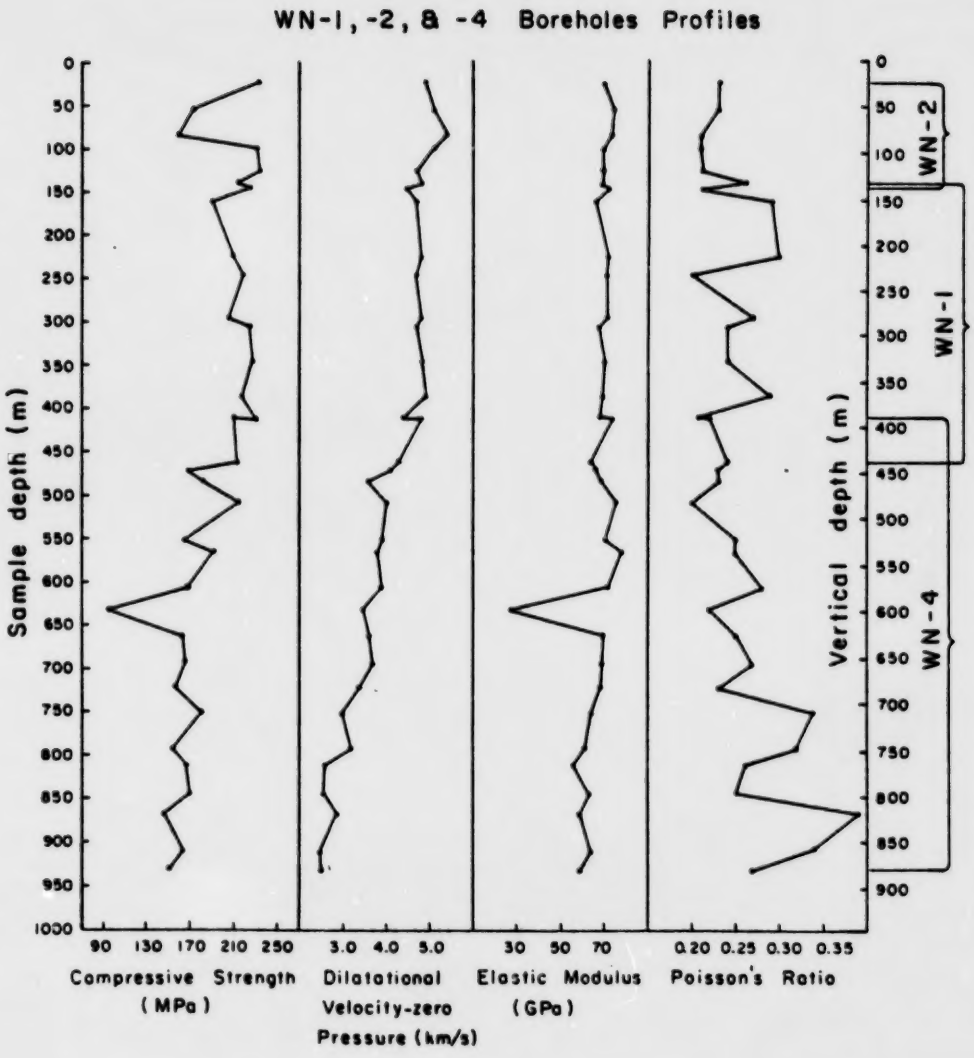

Figure 2: Uniaxial Elastic Properties and Dilatational Wave Velocity Profiles for Borehole WN-1, WN-2 and WN-4

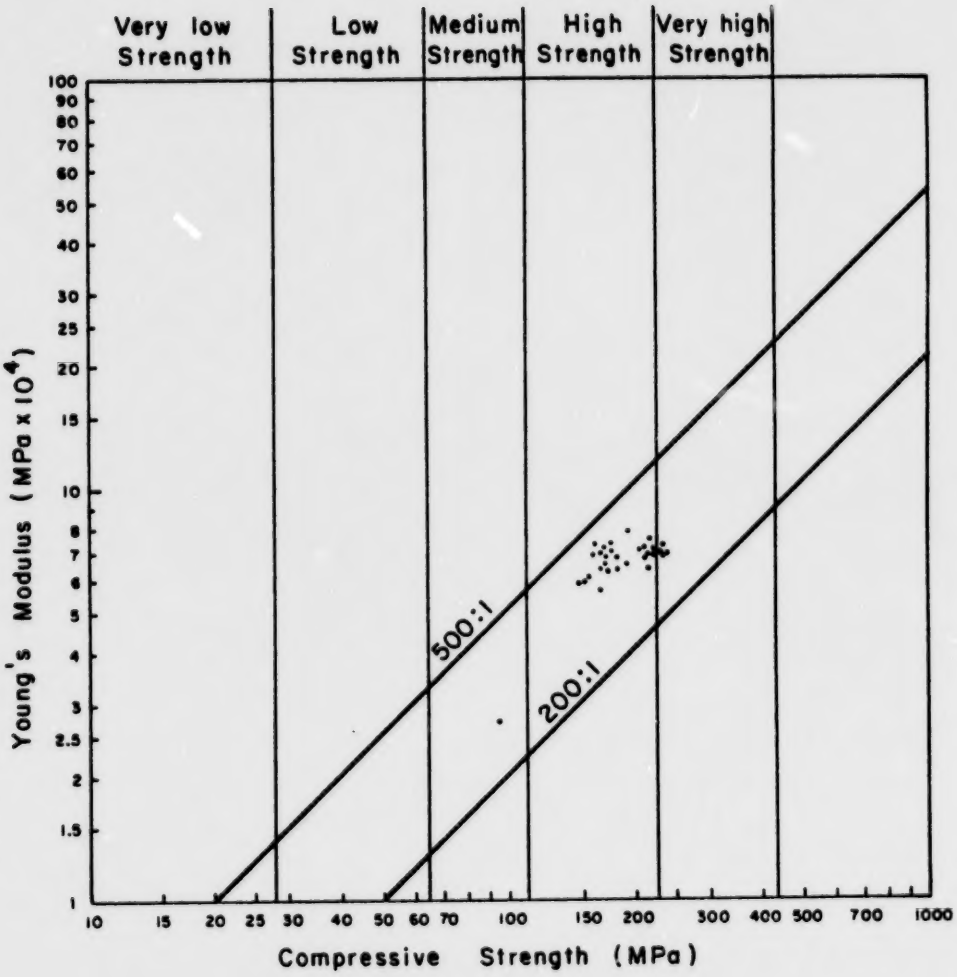

Figure 3: Engineering Classification for Intact Rock for Borehole WN-1, WN-2 and WN-4 samples

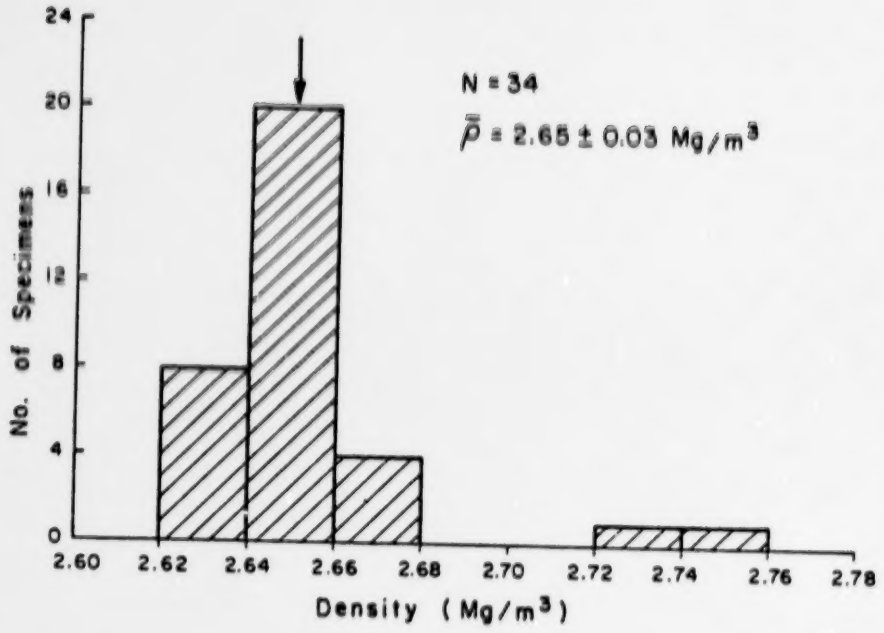

Figure 4: Histogram of Density for WN-1, WN-2 and WN-4 samples

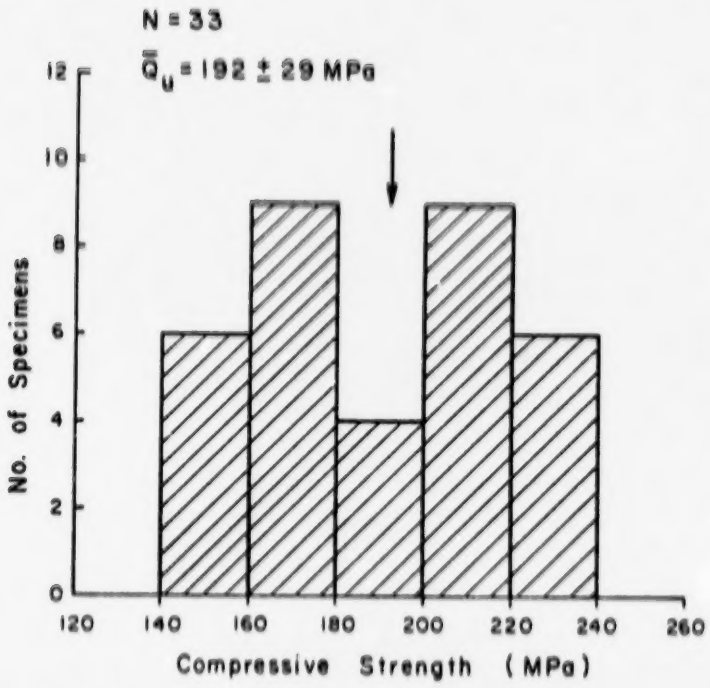

Figure 5: Histogram of Uniaxial Compressive Strength for WN-1, WN-2 and WN-4 samples

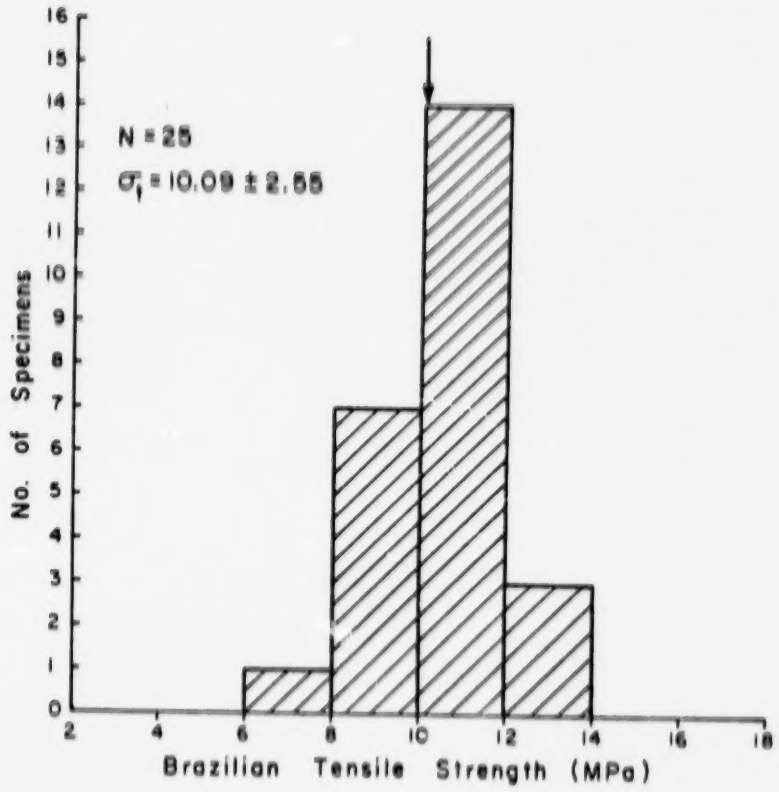

Figure 6: Histogram of Brazilian Tensile Strength for WN-1, and WN-4 samples

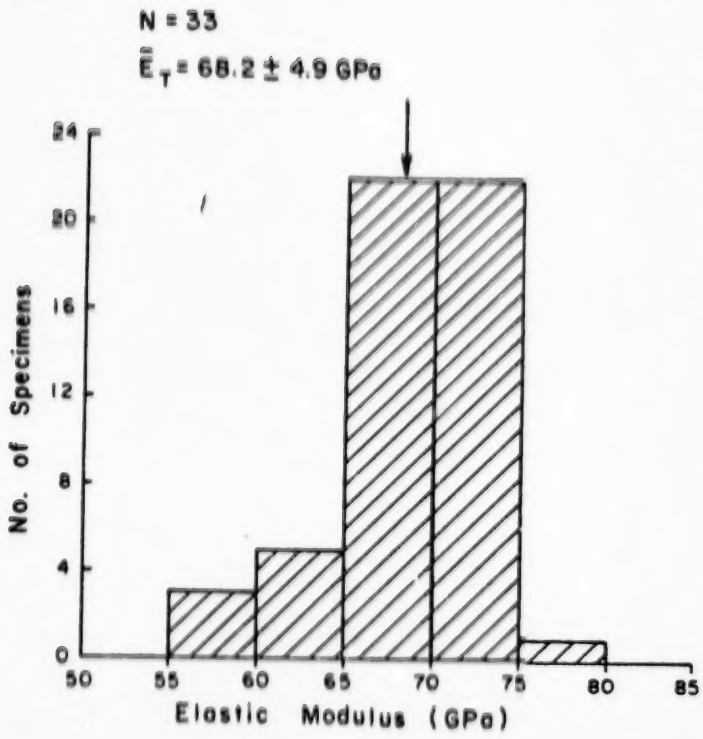

Figure 7: Histogram of Young's Modulus for WN-1, WN-2 and WN-4 samples

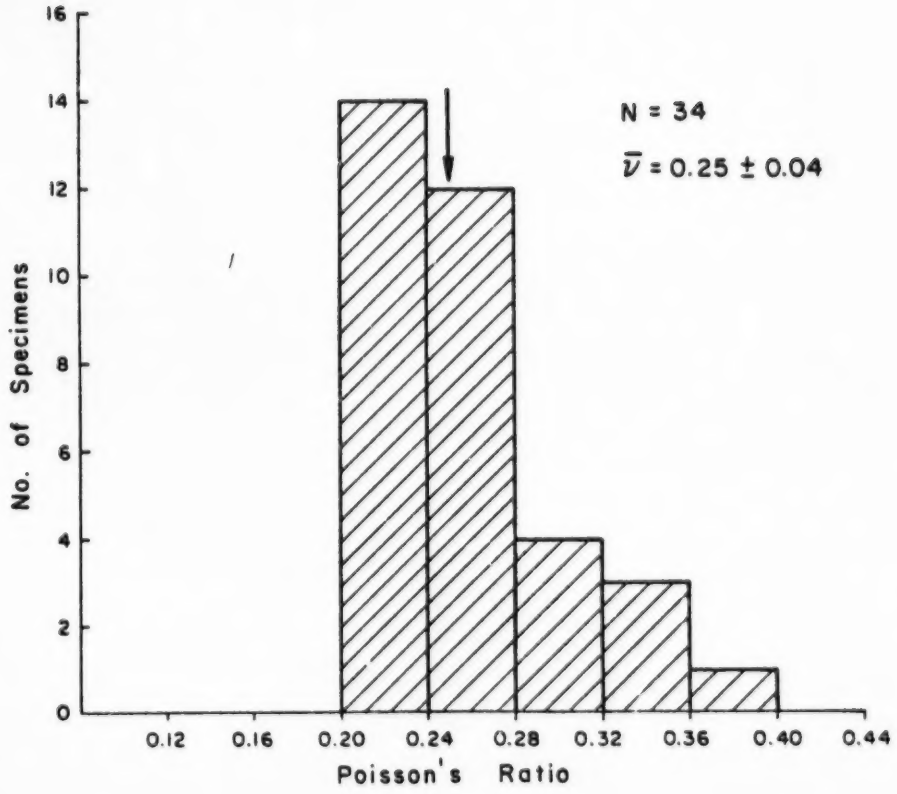

Figure 8: Histogram of Poisson's Ratio for WN-1, WN-2 and WN-4 samples

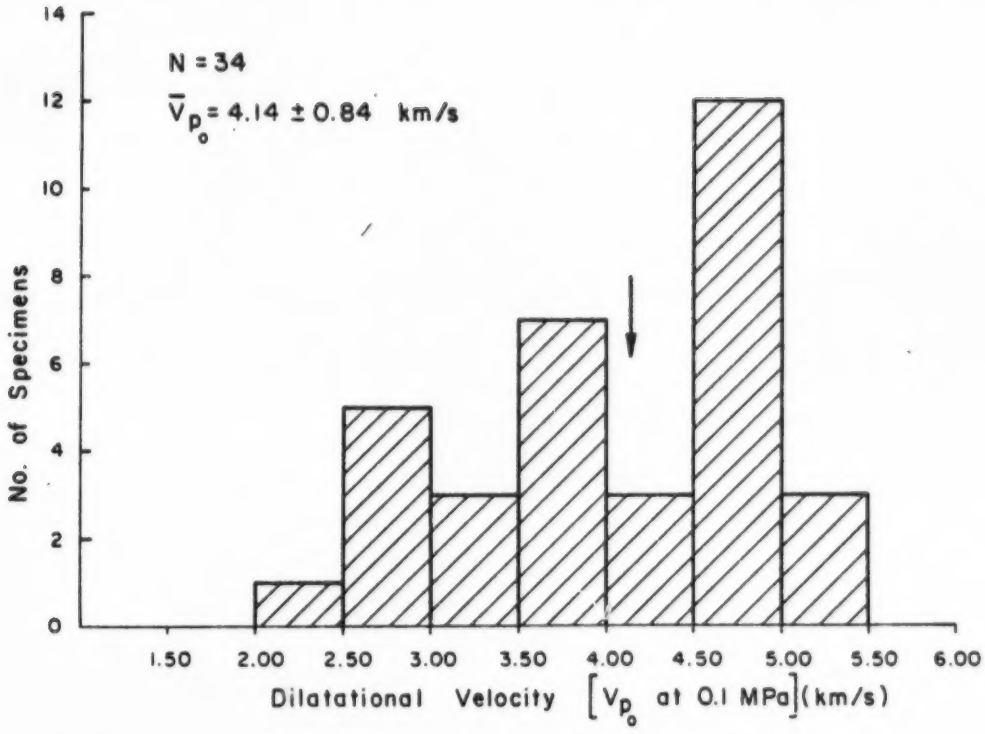

Figure 9: Histogram Zero Pressure compressive Wave Velocity for WN-1, WN-2 and WN-4 Samples

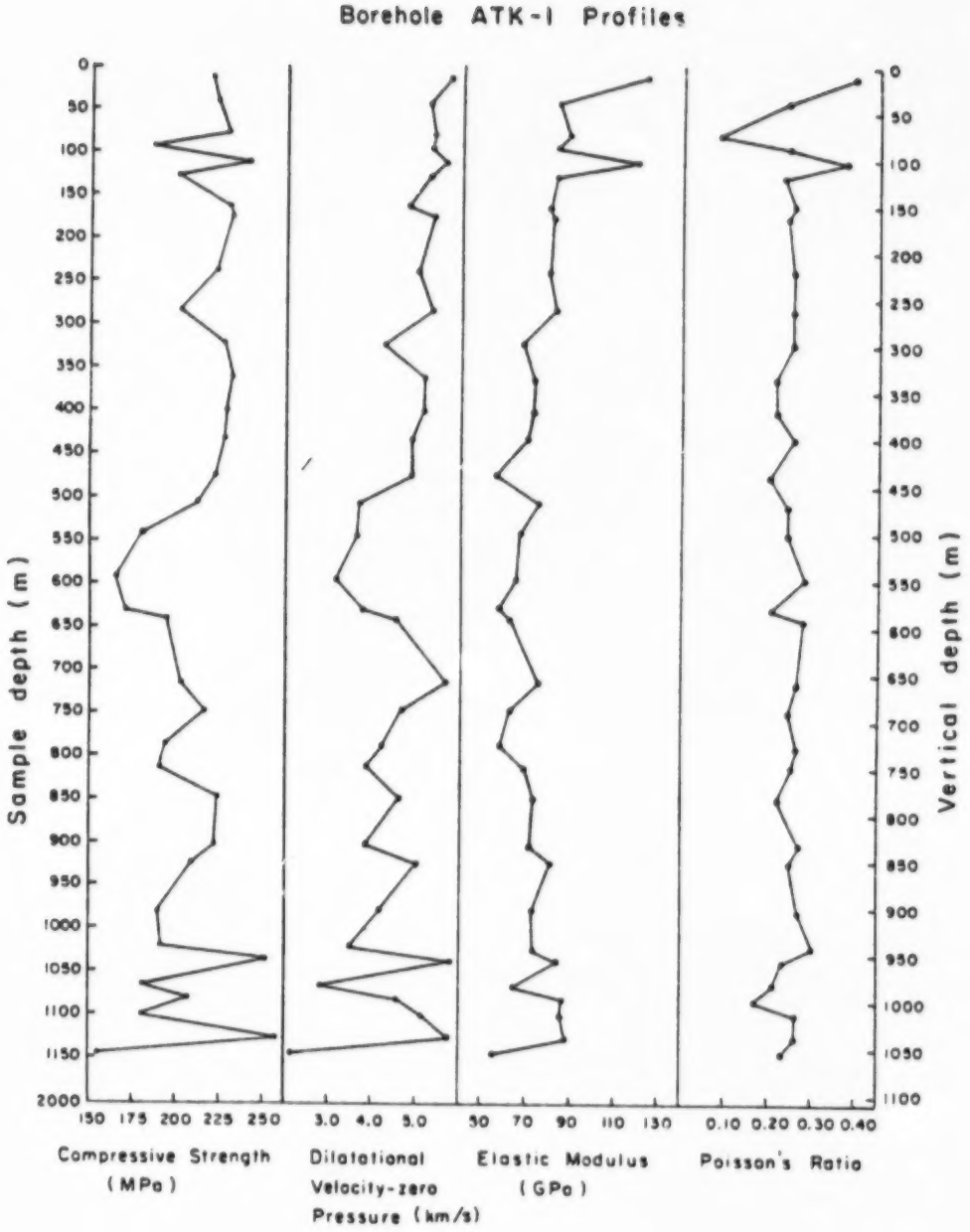

Figure 10: Uniaxial Elastic Properties and Dilatational Wave Velocity Profiles for Borehole ATK-1